

CREEP TESTS OF LAMINATED RUBBER BRIDGE BEARING

Ju OH¹, Hie-Young JUNG², Seong-Kyu PARK³, Gi-Yeol LEE⁴

¹Unison Research and Development Center, Cheonan, Choongnam, Korea

²University of Seoul, Seoul, Korea

³Taegu University, Kyungans, Kyungpukm, Korea

⁴Saman Research and Development Center, Gwacheon, Gyeonggi-do, Korea

oju1030@paran.com

ABSTRACT

Isolated structures use devices such as high damping rubber bearing(HDRB), lead rubber bearing(LRB) and natural rubber bearing(NRB) in order to dramatically reduce the seismic forces transmitted from substructure to superstructure. The laminated rubber bearing is the most important structural member of a seismic isolation systems. The basic characteristics of rubber bearings have been confirmed through compression test, compressive shearing tests and creep test. This paper presents the results and analysis of a 1000hr, ongoing creep test conducted at 7.5Mpa, 8.37Mpa in our laboratory. The long-term behavior of bridge bearings, such as laminated rubber bearings, will be discovered through a compression creep test subjected to actual environmental conditions. These tests indicated that the maximum creep deformation is about 0.3~1.92% of total rubber thickness.

1. INTRODUCTION

The Bridge Bearing System should properly perform below two functions : one is to resist against vertical applied load and deliver the load to the substructure, and the other is to resist against horizontal force and displacement of sub-and-super structure. These two functions are critical factors directly related with the horizontality of bridge structure. In consideration of durability of the Laminated Rubber Bearing, the long-term creep deformation made by rubber layers aging by oxidization and also by axis compress stress for long-term is highly important. However, it is hard to exactly estimate its data, since creep deformation is influenced by the loading time of bridge upper structure and temperature condition. In this regards, vertical deformation by long-term creep of the LRB are usually not considered at the time of design. Generally, the performance test for the Seismic isolation system like Laminated Rubber Bearing is executed by special test such as compressive test or compressive-shear test on the test specimen

According to the previous researches, the creep test were executed on rubber test specimens with separated to Chloroprene(CR) and Natural Rubber(NR). However, the properties of specimen's rubber material can be analogized but cannot be defined as the estimation of the Laminated Rubber

Bearing. Beside, C.J. Deham, R.A.Waller⁽¹⁾ have estimated 100 years after creep deformation on the Laminated Rubber Bearing designed to isolate the buildings from the vibration by the subways by measuring its deformation changes for 15 years. But, it is not much effective since it takes too much time to estimate the results by measuring data.

In this research, the creep test has been executed by using three types of Laminated Rubber Bearings, i.e, High Damping Rubber Bearing(HDRB), Lead Rubber Bearing(LRB), Natural Rubber Bearing(NRB) for 100 hours and the test result analyzed properties of creep change of Laminated Rubber Bearing. Also this research forecasts the durable span of structure after 60 year and 100 year's use respectively. It is necessary the clearly identify the properties of creep of Laminated Rubber Bearing under the high compression stress condition of real seismic isolation structure. In this regards, this research estimates and analyzes long-term deformation through creep test according to the types of axis stress and Laminated Rubber Bearings. After measuring rubber's expansion and compression as to the temperature changes, the test results estimates that the creep amount will not exceed 10 % of the total rubber thickness after 100 year's use.

2. TEST SPECIMENS

High Damping Rubber Bearing(HDRB), Lead Rubber Bearing(LRB), Natural Rubber Bearing(NRB) used on the tests are sorts of seismic isolation system, and they are designed to be proper to the dynamic character of bridge and buildings and they are laminated with rubber and armature plate. However, compared with other specimens, LRB has lead plug insulated central inside of specimens. HDRN and LRB are seismic isolation bearings with Energy dissipated per cycle (EDC), but NRB has relatively lower Energy dissipated per cycle (EDC) than above two specimens.

Specimens used on creep test and fatigue test are designed to be satisfied under various conditions : serviceability limit state by the design compress force, resist force against wind load and the ultimate limit state by the earth quakes. The specimens used on this research are manufactured as standard specimen specified on the ISO 22762. The specimen's section shape and composition are as following Fig. 1.

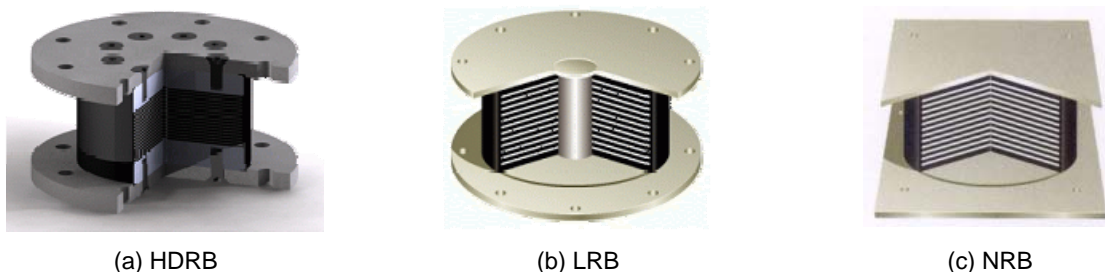


Fig. 1 Inside section shape of the test specimen

Five Laminated Rubber Bearing test specimens used on the test are specified as Fig.2, i.e. Table. There is difference on the size of the specimens, but their main compositions are natural rubbers. As

described on the Fig.3, there are three kinds of specimens : No.1, No.2, No.3 are High Damping Rubber Bearing (HDRB) which has a damping to the rubber itself, and No.4 is Lead Rubber Bearing(LRB) which has lead insuled inside of rubber bearing, No 5. is geneal Natural Rubber Bearing(NRB). The specimen's diameter includes rubber outside thickness 10mm, and inner layer thickness of laminated rubber is 2mm, 3mm respectively, and inner layer thickness of laminated plate is 3mm. S_1 is the Primary shape factor , i.e, ...the ration of load square to the free surface square including one hole inside the subber layer. S_2 is the Secondary shape factor which represent the effective width ratio against total thickness of inner rubber. Each shape factor is calculated by Eq.(1).

$$S_1 = \left(\frac{D_s - D_h}{4t_i} \right), \quad S_2 = \left(\frac{D_s}{nt_i} \right) \quad \text{Eq.(1)}$$

Here, D_s : Diameter of inner plate D_h : Diameter of inner hole t_i : thickness of a rubber layer n : number of rubber layer

Table 1 Overview of laminated rubber bearing

Specimen	Diameter	Rubber thickness	Number of layers	S_1	S_2	Axial stress	Shear Modulus(G)
No.1	250mm	2mm	25	29.7	5	7.5MPa	0.8
No.2	250mm	2mm	25	29.7	5	7.5MPa	0.8
No.3	250mm	2mm	25	29.7	5	7.5MPa	0.4
No.4	259mm	3mm	29	21.6	3	10.8MPa	0.4
No.5	269mm	3mm	31	16.6	2.8	8.4MPa	0.4

HDRB:No.1~No.3, LRB: No.4, NRB:No.5

Thickness 10mm of a protection rubber layer is inclusive.

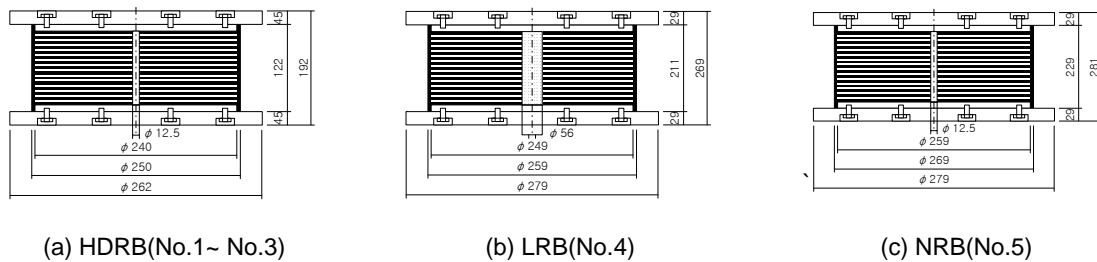


Fig.2 Specimen type



Fig.3 Creep and Fatigue test specimen

3. EXPERIMENTAL METHOD

Fig. 4 Fatigue testing machine used to execute the creep test on the laminated rubber bearings. The Force displacement of testing machine is horizontal displacement $\pm 200\text{mm}$, and available to vertical load $\pm 2000\text{kN}$. Deviation of compressive load is less than 3 %, and detail size of testing machine is described on Table 2.

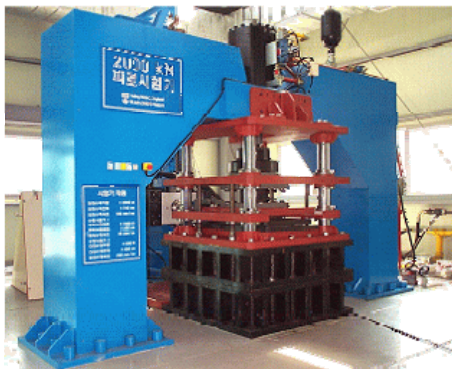


Fig. 4 Fatigue testing machine



Fig. 5 Condition of the creep experiment

Table 2 Overview of fatigue tester

	Max. Load	Max. Stroke	Max. Speed
Vertical	$\pm 2000\text{kN}$	$\pm 100\text{mm}$	100mm/sec
Horizontal	$\pm 500\text{kN}$	$\pm 200\text{mm}$	250mm/sec

The latest performance test standard of the Laminated Rubber Bearing is ISO 22762(Elastomeric Seismic-protection Isolations). ISO 22762 introduces the LRB, one kind of seismic isolation system used for protecting bridge or building from the damage of earthquake, in three parts. Part 1⁽⁴⁾ describes the test procedure of the Laminated Rubber Bearing, Part 2⁽⁵⁾ and Part 3⁽⁶⁾ respectively describes the design standards and product inspection standards. In this research, we have

manufactured the specimens and executed the tests according to the ISO 22762-Part 1. In addition, we executed the creep test using same specimen after performing various kinds of dependence test such as compress property, shear property, as suggested by ISO 22762.

The creep test is the test to figure out the deformation of the Laminated Rubber Bearing under constant compression for long term without shear train. The test was performed on the specimens passing 48 more hours after their manufacturing under the stable condition for 24 more hours at room temperature. We measured creep of Laminated Rubber Bearing for more than 1000 hrs, and also measured as long term as possible to eliminate the unreliability. We measured the creep at minimum 10 points during same time period as $10^0 \text{ hr} \sim 10^1 \text{ hr}$, $10^1 \text{ hr} \sim 10^2 \text{ hr}$, $10^2 \text{ hr} \sim 10^3 \text{ hr}$. The specimen No. 1 tested under real temperature condition, and other two specimens were tested under the constant temperature condition as $23 \pm 2^\circ\text{C}$ to figure out the influence to the long-term deformation of laminated rubber bearing according to the temperature condition. The vertical displacement of specimen was measured by installing two high sensitive displacement devices, and vertical displacement data is average amount of two displacement device's data. Test condition is as Fig. 5. The vertical load was loaded as design compressive stress for 1 minute. The force load of specimens compressed as below : No. 1 ~ No.3 is 370kN each, and specimen No. 4 is 580 kN, and specimen No. 5 is 450kN. The deviation of compressive load is less than 3%, and test condition was maintained as real condition as possible.

4. EXPERIMENTAL RESULTS

Fig. 6 shows the change of vertical displacement right after loading design compressive load at the temperature changing condition. This vertical displacement is relative displacement to the vertical displacement against LRB. This figure would be reduced with laminated rubber's expansion.

Under temperature changing condition, it is necessary to convert the temperature to compare the displacement figure of the specimen No.1 with another specimen which tested under the constant temperature as $23 \pm 2^\circ\text{C}$. The specimen No. 1 tested under air temperature changing condition was converted by using coefficient of linear thermal expansion α to vertical displacement of specimen as Eq.(2).

$$\Delta H_{23} = \Delta H_T + nt_r(T - 23)\alpha \quad \text{Eq.(2)}$$

Here, ΔH_{23} means a change to the vertical displacement at 23°C , and ΔH_T means a change to the vertical displacement at $T^\circ\text{C}$. T means the surface temperature($^\circ\text{C}$) of test specimen, and α means the coefficient of linear thermal expansion(23°C at $T^\circ\text{C}$). The coefficient of the thermal expansion of the specimen No. 1 at each time interval is as Table 3, and the creep deformation rate is calculated as to the Eq.(3).

$$\varepsilon_{cr} = \frac{\Delta H_{23}}{nt_r} \times 100 \quad \text{Eq.(3)}$$

Table 3 Thermal coefficeint α (mm/°C)

Time	1~100hr	101~1000hr
Linear gradient	-0.000371094	-0.000329716

The calculation on creep deformation amount of specimen No. 2 ~No. 5 which test temperature constantly maintained as $23 \pm 2^\circ\text{C}$ can be draw out coefficient a and b from functional equation like Eq.(4). Then it is substituted to Eq.(5) and draw out the creep deformation of laminated rubber bearing after 60 years and 100 years uses respectively. Here, ε_{cr} means the percentage of total rubber thickness to the creep amount after decades use, and t means the unit hour.

$$\log_{10} \varepsilon_{cr} = \log_{10} a + b \log_{10} t \quad \text{Eq.(4)}$$

$$\varepsilon_{cr} = at^b \quad \text{Eq.(5)}$$

After measuring the vertical displacement with loading design compressive load for 1000hr under different conditions by using 3 types of Laminated Rubber Bearings, the test results have found that the Specimen No. 1 tested under air temperature condition have 2.7 times and 3.9 times respectively of vertical deformation than those of same types of test specimen No. 2 and No. 3 tested under constant temperature. In case the test condition like temperature was same, the Specimen No. 3, i.e, high damping rubber bearing has the fewest vertical deformation. Fig. 6 shows the test result on each specimen for 1000 hours.

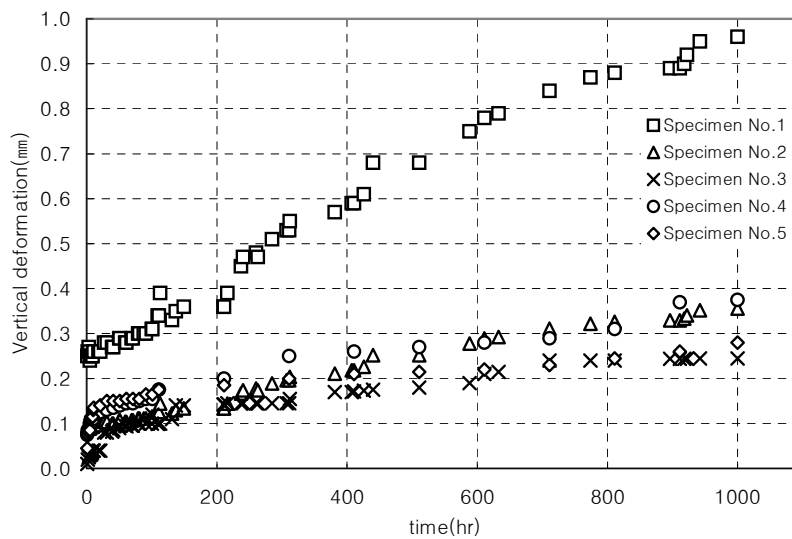


Fig. 6 Changes in the vertical deformation

Fig. 7 shows the change of the vertical displacement as to the test temperature change after loading the design compressive load. Specimen No.1 tested under atmosphere temperature shows the sharp increase of vertical deformation as temperature dropping. On the other hands, the specimen No.2 tested under the constant temperature as $23 \pm 2^\circ\text{C}$ shows relatively stable and gradual increase of vertical deformation. This time, vertical displacement also shows repeated compression and expansion of rubber along with temperature changes. Fig. 8 shows the vertical deformation amount according to the temperature changes. As to above fig. , the lower the temperature, vertical displacement amount increases, but the higher the temperature, vertical displacement amount decreases. Fig. 9 and Fig. 10 shows the mutual relationship between the shear modulus(G) and primary shape factor(S_1). In case the section property and the shape factor are same, the greater shear modulus is, the creep amount increases. Also, the greater primary shape factor(S_1), the vertical rigidity increases and the creep amount decreases. However, the specimen No.4 in the Fig. 10 has lead plug insulated in the central laminated rubber, this case creep amount increases even the shape factor(S_1) increases after 100 hr passed. Compared with same size specimen No.5, its axis compressive stress is big, but the space receiving compressive load, on the other hands, decrease due to its inside lead plug so its vertical deformation increases after certain time passed.

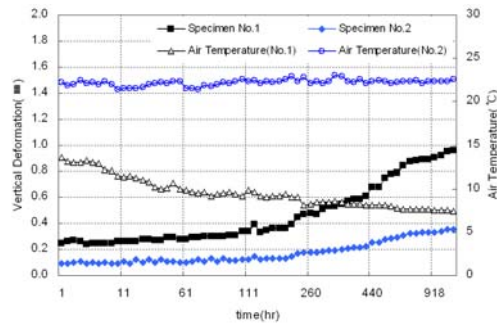


Fig. 7 Relationship between the vertical deformation and temperature

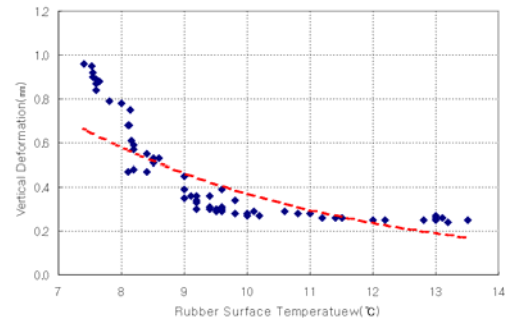


Fig. 8 Relationship between the vertical deformation and temperature for the fluctuation of the compressive load

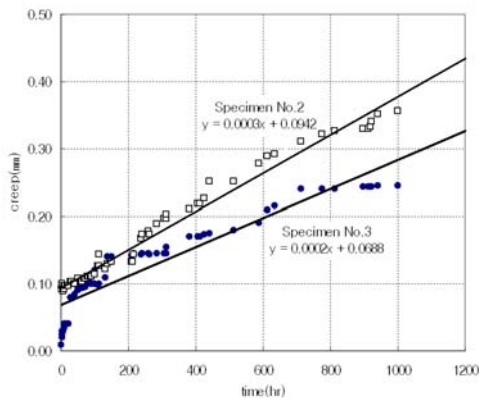


Fig. 9 Effect of Shear modulus(G)

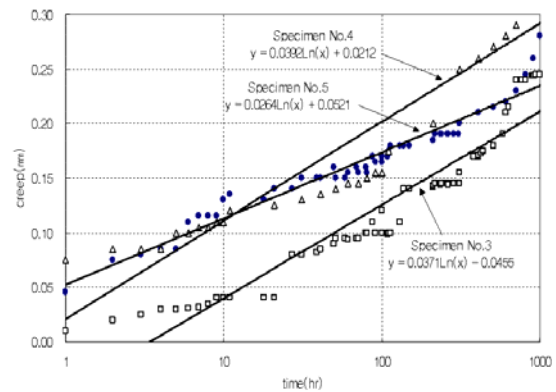


Fig. 10 Effect of Primary shape factor (S_1)

Table 4 shows the Semi-logarithmic time axis of creep amount after 60 years and 100 years 's use according to the above equation. It is estimated that the creep amount of high damping rubber bearing(No.1, No.2, No.3) under compressive stress status 7.5Mpa after 100 year's as 0.56 ~ 2.92 mm . It is also estimated that the Lead Rubber Bearing(No.4)'s creep amount as 1.16 mm and the Compressive Stress Rubber Bearing as 1.08 mm. According to the Oh et al.⁽³⁾ research, the creep on rubber visually occurs as many years passed, and it decreases as the Primary shape factor (S_1) increases and depends on the S_1 regardless of the certain axis stress. If this is correct, the creep test on the Laminated Rubber Bearing should be performed for much more period, and be studied through long-term creep test by converting shape factor. This research estimates the deformation amount(mm) after 60 year and 100 year's durable life of structure through the creep deformation test usually not being considered at the time of Laminated Rubber Bearing's design. On Table 4, it shows the creep data and its change rate after 60 year and 100 year's use by using vertical displacement data of Laminated Rubber Bearing after loading design compress load for 1000 hrs. The long-term creep estimate was calculated as the Semi-logarithmic according to the Eq.(4) and Eq.(5) like Fig.11.

Subject to the HDRB test specimen No. 1,2,3, it is expected to deform as 0.54 mm, 1.54mm and 2.77 mm respectively after 60 year's use under the design compress stress condition. And the deformation rate of each test specimen is expected to deform from minimum 1.08% to maximum 5.54 % after 60 year's use. Here, the creep deformation rate calculated by dividing estimated creep data calculated based on the test results by total rubber layers thickness.

Table 4 Estimated creep value(mm)

specimen			1000hr	60 years after	100 years after	condition
HDRB	No.1	creep(mm)	0.96	2.77	2.92	air temperature
		strain ratio(%)	1.92	5.54	5.84	
	No.2	creep(mm)	0.36	1.54	1.62	laboratory temperature (23±2℃)
		strain ratio(%)	0.72	3.08	3.24	
	No.3	creep(mm)	0.24	0.54	0.56	
		strain ratio(%)	0.48	1.08	1.12	
LRB	No.4	creep(mm)	0.38	0.98	1.03	
		strain ratio(%)	0.44	1.12	1.18	
NRB	No.5	creep(mm)	0.28	1.02	1.08	
		strain ratio(%)	0.3	1.10	1.16	

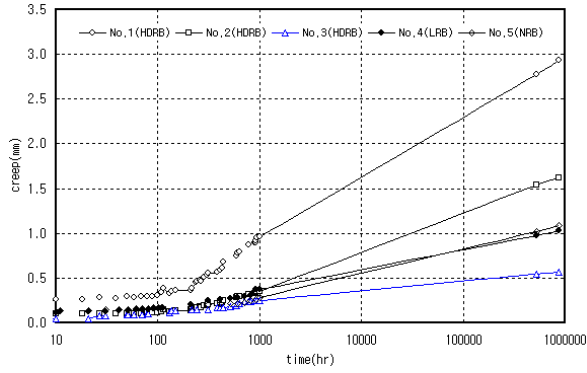


Fig. 12 Comparison of creep(mm)

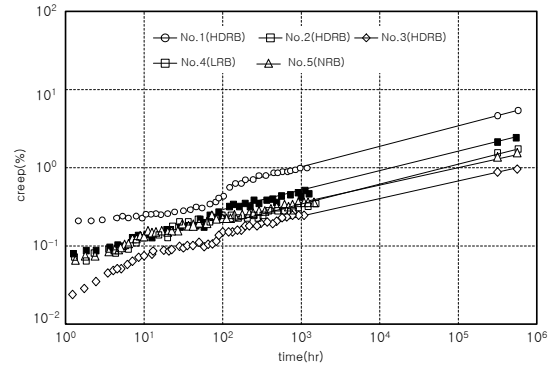


Fig. 13 Comparison of creep rate(%)

5. CONCLUSION

In this research, the creep test was executed to figure out the creep deformation character of LRB, HDRB and LRB, NRB manufactured as to the seismic isolation design that is usually not considered at the time of designing. For this research, we performed the creep test for 1000 hr on three types of laminated rubber bearing : three specimens using high damping rubber, one specimen having lead insulated inside the laminated rubber and one specimen using regular rubber. After the test, we analyzed measurement data and creep changes according to the influence factors such as temperature changes and shear modulus, then estimated the change rate of creep deformation after 60 year's common uses. The summarized the test results are as below :

- 1) The analysis of the relationship between creep vertical deformation and temperature based on the test results on the specimens of the laminated rubber bearing under the atmosphere temperature and room temperature conditions respectively revealed that the higher the temperature is , the fewer chance of creep deformation ; the lower the temperature is, the more chance of creep deformation.
- 2) In case the section size and the shape factor are same, the greater shear modulus is, the creep amount increases. Also, the greater primary shape factor(S_1), the vertical rigidity increases and the creep amount decreases.
- 3) The calculation on creep deformation amount using three types of five specimens of laminated rubber bearing under the compressive load for 1000 hours estimates the deformation 60 years after as 0.56~2.92mm. Also, the creep change rate is converted maximum 5.84% on HDRB No. 1 tested under the air temperature condition, and creep deformation will be made less than 10 % of natural rubber thickness.
- 4) The Laminated Rubber Bearing used in this research is exposed to outside environmental changeable factor such as oxidation in air, ozone for longer period than of the one on the real bridge system. In this regards, long-term creep test considering outside environmental factors that could influence on creep deformation should be executed.

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